# Final report

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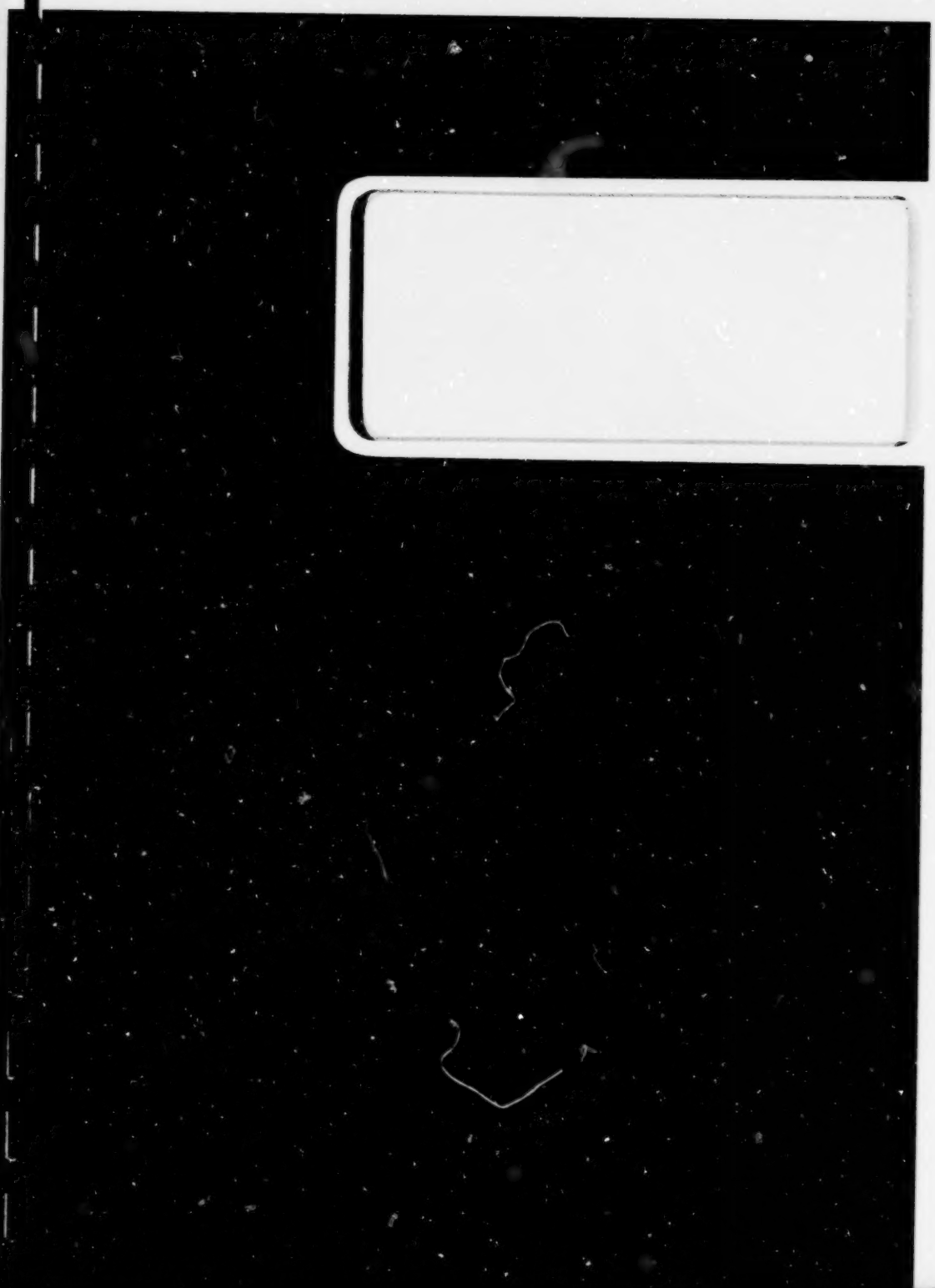

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ONTARIO RESEARCH
FOUNDATION

**Gartner Lee Associates Limited**

Consulting Engineering Geologists and Hydrogeologists

Toronto-Buttonville Airport ■ Markham, Ontario ■ L3P 3J9 ■ 416-477-8400
Telex - 06-980278

# ATMOSPHERIC DISPERSION INFLUENCES
# GOLDEN HORSESHOE

FOR

GARTNER LEE ASSOCIATES LIMITED

BY

ONTARIO RESEARCH FOUNDATION

PROJECT NO. 83-1003

MAY, 1983.

**Gartner Lee Associates Limited**

Consulting Engineering Geologists and Hydrogeologists

Toronto-Buttonville Airport ■ Markham, Ontario ■ L3P 3J9 ■ 416-477-8400
Telex - 06-986278

May 13, 1983.

Ontario Waste Management Corporation,
2 Bloor Street West,
11th Floor,
Toronto, Ontario,
M4W 3E2.

Attention: Mr. B.D. Mitchell, Ph.D.,
Director,
Corporate Planning and Development

Dear Sir:

Re: Final Report - Atmospheric Dispersion in the Golden Horseshoe

We are pleased to submit the final report entitled "Atmospheric Dispersion in the Golden Horseshoe" prepared on our behalf by the Environmental and Chemical Engineering Divisions of the Ontario Research Foundation. The report describes various atmospheric dispersion influences within the Golden Horseshoe, graphically portrays their occurrence in the geographic region under study and provides the rationale for considering such influences in the identification of candidate areas for an incineration facility.

We have reviewed the report and trust that you will find it to your satisfaction.

Yours very truly,

GARTNER LEE ASSOCIATES LIMITED

Grant Anderson

E.G. Anderson, P Eng.,
Project Director.

DSO:jcm

c.c. Dr. S. Barton, ORF
File: 83-1003

# ATMOSPHERIC DISPERSION INFLUENCES: GOLDEN HORSESHOE

Prepared by:

S.C. Barton
M. Dobson
Environmental & Chemical
Engineering Division

for

Gartner Lee Associates Limited

May 10, 1983

ONTARIO RESEARCH FOUNDATION

SHERIDAN PARK RESEARCH COMMUNITY

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# ATMOSPHERIC DISPERSION INFLUENCES: GOLDEN HORSESHOE


## SUMMARY

The primary objective of this study was to provide information on atmospheric dispersion phenomena in the Golden Horseshoe area. Specific components of the study were:

- preparation of a concise description of the potential effects of lake breezes, urban heat islands, and topography on air pollution dispersion.
- statement of rationale for using these air dispersal constraints as an important factor in identifying suitable sites for an incinerator.
- preparation of a constraint map showing the potential regions of occurrence of these phenomena in the Golden Horseshoe.


## Elaboration of Major Climatological Influences

Lake breeze phenomena can be experienced along all shores of Lake Ontario and Lake Erie during the day, with the effect being more pronounced during the summer and somewhat less intense during the spring and fall months. Breezes from the lake to the land promote the formation of an internal boundary layer which increases in depth with distance from the shoreline. The pollutants in a plume which encounters this boundary layer are brought down to ground level rapidly, resulting in potentially high ground level concentrations (referred to as fumigation). This situation can be avoided by not locating facilities within approximately 5 kilometres of the lakeshore. Lake breezes also tend to recirculate pollutants which

are not brought to ground level by fumigation. However, the direct fumigation of emissions is the most important mechanism whereby lake breezes can result in high ground level pollutant concentrations. Regional onshore winds, in the absence of a lake breeze, can create an internal boundary layer, also conducive to fumigation from shoreline stacks. The maximum total occurrence of both lake breezes and regional onshore winds can be expected approximately 30% of the time in the summer, approximately 25% of the time in the spring and approximately 20% of the time in the fall. Winter fumigation events are very rare. These estimates are based upon the assumption of a maximum effective stack height of 100 metres.

An urban heat island occurs when an urban area releases enough heat to create a substantial temperature differential with the surrounding rural regions and thus creates a convective circulation. Under relatively calm conditions, pollutants are recirculated within the turbulent atmosphere of the urban centre. This condition is especially significant at night when the urban air, and pollutants, are trapped on all sides by cool stable "rural" air. On windy days the urban plume is transported downwind where relatively high ground level concentrations can result if the plume loops to the ground in a buoyant atmosphere. At night the urban plume can travel as a relatively undispersed plume for 10's of km in the stable air before encountering unstable air and dispersing or fumigating. This usually occurs on the following day. The urban heat island is strongest during summer months, although present all year, but is especially significant to air quality during nocturnal hours under conditions of relatively light winds.

Pollutants frequently become trapped below a prominent feature such as the Niagara Escarpment. The effects are present during all seasons of the year. Very high winds may disperse pollutants but the possibility of fumigation against the feature is present under most wind conditions.

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A number of regions in the Golden Horseshoe experience the effects of various combinations of these influences. An urban centre located on the shoreline (Toronto, for example) can strengthen and create a 24-hour lake breeze circulation cell, recirculating the pollutant emissions from the urban centre. A prominent topographic feature such as the Niagara Escarpment can trap pollutants emitted near the base of the feature, even under relatively good dispersion conditions. Pollutants from an urban centre near such a feature can be restricted on windy days as well. The combined occurrence of a lake breeze and a topographic feature can adjust the circulation cell of the lake breeze, with the potential to create poor dispersion conditions at the base of the feature. The city of Hamilton is a prime example of the combination of all three factors. Topographic features combine with the lake breeze and the urban heat island to quite frequently result in extended periods of high pollutant levels. Local emissions become entrained in the lake breeze circulation cell which is further restricted by the escarpment and reinforced by urban heating. Virtually all incidents of the Alert Level of the Ontario Air Pollution Index being reached in Hamilton are a consequence of this combination of influences.

Rationale for the Use of Air Dispersal Constraints

Emissions to the atmosphere represent the major potential environmental impact that might arise from the operation of an incinerator. The impact mechanism consists of three components: emission, dispersion and receptor impact. Optimal control of emissions at the source through the use of best-available emission control technology must be viewed as the most important component of any control strategy to minimize potential impact. However, standards that can be used to precisely specify the performance of emission control equipment are not yet defined for many of the trace contaminants which might be emitted from a hazardous waste incinerator. In addition to incorporating sound engineering principles to ensure minimal emissions of such contaminants, it is also important to avoid areas which are known to be

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subject to atmospheric conditions which inhibit good dispersion of emissions to the atmosphere. The selection of sites which avoid adverse dispersion conditions is one of the more cost-effective avoidance measures that can be used. In so doing, both the frequency and intensity of periods of potential adverse impact are minimized.

Constraints Within the Golden Horseshoe Area

The portions of the Golden Horseshoe area affected by the major air dispersal influences have been summarized in the form of a 1:126,000 map, enclosed in the pocket on the back cover of this report. Areas where adverse dispersive conditions can occur can be summarized as follows:

- Urban areas with a population greater than approximately 40,000.
- Land within 5 km of the shorelines of Lake Ontario and Lake Erie.
- Lands near the base of the Niagara Escarpment.

Combined influences, which increase the probability for poor dispersion, can occur in such areas as Burlington, Hamilton and Toronto.

The remaining lands within the Golden Horseshoe are not considered to be under the influence of atmospheric constraints. However, the need exists to also consider the relative potential for impingement of emissions on downwind receptors. Such considerations, as well as studies examining the potential impact of unforeseen events such as accidental spills or explosions will be components of future studies.

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## 1. INTRODUCTION

This report elaborates on air dispersal phenomena as they pertain to the Golden Horseshoe region of Southern Ontario. The Phase I report (Primary Environmental Information, Part 4: Climatology - Volume 1), submitted in September 1982 to OWMC, provided an overview of the climatological and meteorological conditions in Southern Ontario, and identified those specific effects or conditions which should be considered in the selection of a site for a hazardous waste management facility. Each of these influences are addressed in further detail in this report in both a general context and with specific reference to the Golden Horseshoe area. The rationale behind using air dispersion as a primary constraint in the siting of an incinerator is also discussed.

The prediction of how well emissions to the atmosphere will be dispersed in a large region such as Southern Ontario requires, initially, a brief understanding of the large scale atmospheric phenomena over the area. Stagnant anticyclones, for example are characterized by high pressure and clear weather, but also by low wind and poor dispersion conditions. Anticyclones tend, in general, to be especially persistent in autumn and early winter. Cyclones, on the other hand, are accompanied by low pressure and generally stormy weather, resulting in good dispersion conditions because of the generally turbulent atmospheric conditions which prevail (Hewson and Olsson, 1967).

Other more specific influences can occur within, or as part of, these larger scale influences. For example, lake breeze flows often are observed under essentially stagnant anticyclone conditions over the Great Lakes. The urban heat island phenomenon can occur under various large scale atmospheric conditions, although the influence is intensified under anticyclonic conditions. Topographic features downwind of a pollutant source can be expected to retard or complicate pollution dispersal to varying degrees, during the presence of all weather systems, but such effects become especially important when

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coupled with meteorological influences that result in poor dispersion.

In Appendix I, a series of annotated diagrams are used to outline in general terms the basic physical mechanisms which give rise to lake breeze, urban heat island and topographic effects. More detailed and specific discussions of these phenomena are provided in the sections that follow with reference to specific examples of these effects which occur in the Golden Horseshoe. Perusal of Appendix I prior to reading the remainder of the report is advocated and the individual figures are cited where appropriate in the text.

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## 2. ELABORATION ON MAJOR CLIMATOLOGICAL INFLUENCES

### 2.1 Lake Breeze

Differential heating of the air, giving rise to a horizontal pressure gradient, is a primary driving motion in the atmosphere. Air tends to flow from high to low pressure, i.e., from a cold toward a warm region. Local winds such as lake breezes are caused by local temperature differences (Figure I-1). As soon as the motion is initiated, several other forces act on the moving air parcel. In the Northern Hemisphere the rotation of the earth deflects the motion of air to the right (the Coriolis Effect, as illustrated in Figure 1-2). Near the earth's surface there is a frictional boundary layer in which the air movement is retarded due to interaction with the underlaying surfaces.

The depth of this boundary layer depends on the stability of the air. If the air mass is warm in its lower layers and cold above, the air is unstable and intense vertical mixing takes place as the warm air rises and the cold air descends. Atmospheric contaminants will be distributed within this boundary layer which can be several km high; referred to as the mixing height. In the absence of a mixing height (i.e., if the air is stable as a result of lower air being colder than that above), very little vertical mixing takes place. The vertical temperature gradient is thus a measure of the stability of the air (Hewson and Olsson, 1967).

Patterns of atmospheric flow and dispersion near a shoreline are extremely complex and it is difficult to construct detailed models to represent the actual behaviour. The lake breeze is generally initiated between the hours of 0900 and 1100, under relatively clear skies and light or calm regional winds and consists of onshore winds up to a height of 500 m under the return offshore flow. During the warmer seasons the arrival of the lake breeze inland (at 1 km, for example) is accompanied by a sharp air temperature drop of about $2^{o}C$ and a minimum 15% increase in relative humidity, within approximately

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a 15 minute period (Ryznar and Touma, 1981).

In the Golden Horseshoe region of Ontario, the mechanism exists for the generation of lake breeze and land breeze circulations during all months, although the spring and especially the summer months can be expected to record the greatest number of occurrences. From December to March, there is usually a strong thermal gradient conducive to the formation of land breezes between the cold land surface and the relatively warm waters of Lake Ontario during the day and night (Figure I-3), the surface of which rarely freezes over. However, the general atmospheric circulation is usually quite brisk at this time of year, with few nights of clear skies and light winds. The months of April to August experience periods of light regional winds and intense solar heating leading to the existence of a strong thermal gradient between the warm land and the cool lake waters during the day (lake breeze formation), and between the cooled land and the relatively warmer lake waters at night (land breeze formation). During the months of September to November the land to lake thermal gradient is at a minimum . However this is usually the season for periods of high air pollution potential with stagnating anticyclones occurring frequently in the Great Lakes (Munn et al., 1964). The relative magnitude of seasonal shoreline circulation is illustrated in Figure 1-4.

The internal boundary layer characteristically increases in depth with distance inland (Figure I-5). Panofsky and Townsend (1974) conclude that the mean slope is approximately 1:10 during the warm months (10 m horizontally (inland) for every 1 m vertically (up from the surface)). Echols and Wagner (1972) estimated that the mean slope of the internal boundary layer on the Texas coast in June is 1:13. A Brookhaven National Laboratory Study concluded that the slope was 1:4 for the first several hundred metres, levelling off to about 1:100 by 20 to 30 km inland (Raynor et al., 1979). Lake Michigan studies have found a "typical" summer lake breeze cell to extend approximately 20 km inland (Frisken, 1973; Ryznar and Touma, 1981) and out 10 km over the lake. At Nanticoke, it was determined that the internal

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boundary layer maintained equilibrium, i.e., did not further increase in height with distance inland, about 25 km inland during the summer months (Portelli, 1981).

The differentiation between regional and local winds near the Great Lakes is an important consideration. When the regional wind flow is parallel to the coastline, the lake breeze effect is generally very slight, depending on the velocity of the regional winds. When the prevailing regional winds are at right angles to the shore, from lake to land, an internal boundary layer commences at the shoreline and thickens inland under all cloud cover conditions. However, this cannot be described as a lake breeze if a circulation cell is not in evidence. The Coriolis Effect will not shift these regional winds, as it would for a lake breeze. When the regional winds blow from the land to the water, the night-time land breeze is intensified and a better defined boundary layer develops offshore. The day-time wind reversal may or may not occur, depending on the strength of the regional wind and other factors (Munn and Richards, 1964).

The formation and persistence of a lake breeze circulation cell (which may extend up to several km vertically), and the internal boundary layer, is highly dependent on the regional wind characteristics and the sunlight intensity. An incoming bank of clouds could serve to dispel a lake breeze circulation. As well, a lake breeze will not form if the offshore winds are of greater than moderate velocity (under clear skies) or if more than $\sim$ 7/10 of the sky is covered by opaque clouds under calm winds (Ryznar and Touma, 1981). Other related factors which influence lake breeze characteristics include temporal factors, the terrain and water roughness, the temperature differential across the top of the internal boundary layer, the humidity inland, and the profile of the coastline. For example, a wide sandy beach may at times become sufficiently hot to create a double circulation cell, with air flowing towards the beach from both land and water (Munn and Richards, 1964).

A six-year comprehensive programme was undertaken on the eastern shores of Lake Michigan designed specifically to monitor "true" lake breeze characteristics (Ryznar and Touma, 1981). Results indicated that 17% of all summer days could be expected to record a well developed lake breeze circulation cell, whereas 11% and 5% of spring and fall days (respectively) recorded such occurrences. Although Lake Michigan is larger than Lake Ontario and Lake Erie, these figures can be assumed to be relatively representative of the Golden Horseshoe shorelines.

As mentioned previously, light onshore regional winds can promote internal boundary layer formation. Historical data are available for Toronto, Hamilton and St. Catharines, describing the combined frequency of occurrence of such winds and are summarized below.

LIGHT REGIONAL ONSHORE WINDS FOR TORONTO, HAMILTON, AND ST. CATHARINES (1951-1980 MEANS)

| | Toronto (E,SE,S Winds) | | | | Hamilton (NE,E winds) | | | | St. Catharines (N winds) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Season | S | F | W | Sp | S | F | W | Sp | S | F | W | Sp |
| Combined Frequency of Occurrence (%) | 25 | 26 | 17 | 27 | 22 | 21 | 16 | 30 | 9 | 9 | 7 | 10 |
| Mean Wind Speed (m/s) | 3.5 | 4.0 | 4.0 | 4.0 | 3.0 | 3.0 | 4.0 | 3.5 | 3.5 | 4.5 | 5.5 | 3.5 |

(Environment Canada 1981)

Account should be taken of the fact that the formation of an internal boundary layer on the land generally occurs during daylight hours, and that this wind data covers the entire 24-hour period. Therefore, the values must be considered as an over-estimation (~ 2-fold) when used in this context.

A major influence on pollutant dispersion and transport in coastal environments is the presence of these lake/land breeze stabilities and flow reversals. Most large pollutant sources are located

in shoreline environments because of other siting requirements. Fumigation and plume trapping can cause serious degredation to the air quality in the affected regions. When an elevated plume intersects the internal boundary layer, convective turbulence mixes the pollutants to ground level, in potentially high concentrations, or fumigates (Portelli, 1981). Fumigation is generally a function of meteorological conditions (which determine the internal boundary layer structure, etc) and emission parameters. For example, the higher the stack the further inland fumigation will occur with the exception of a stack emitting a plume within or higher than the internal boundary layer. A recent tracer study demonstrated that material emitted into an elevated stable layer at night can be transported out over the water, fumigated to the surface (in about 20 minutes) and returned at ground level to the land on the next day (McRae et al., 1982). Extensive studies have been undertaken in an attempt to study the fumigation patterns of the Nanticoke plume inland of Lake Erie. The two 198 m stacks emit plumes which merge into a single plume downstream, and have been shown to fumigate 7-20 km downwind (Portelli, 1981; Misra, 1980). Often the fumigation zone was discovered to rotate about the source, as a result of the Coriolis Effect. The effect characterized a "true" lake breeze. However, if the fumigation zone remained stationary, the plume was likely under the influence of light regional winds (Portelli, 1981). An internal boundary layer was formed in these cases, but the cell-like circulation which tends to recirculate pollutants was absent.

Emissions from a stack situated along the shores of Lake Ontario or Lake Erie, within the Golden Horseshoe area can be expected to behave in much the same manner as the example described above, with the point of fumigation very dependent on such design factors as stack height, exit temperature and velocity, etc. Evaluations specific to individual sites and facility designs are required to determine the approximate dimensions, magnitude and frequency of fumigations that might occur at a given site.

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## 2.2 Urban Heat Island

An urban heat island can be described as a thermal anomaly having both horizontal and vertical as well as temporal dimensions (Figure I-6). It is characterized by a "plateau" of elevated air temperature sloping away from the city centre, surrounded by a heat "cliff" in the suburban regions where temperatures fall off rapidly. This feature is evident in Toronto where mean annual air temperatures (1951 to 1980) varied by $3^{o}C$ between downtown Toronto and the Toronto International Airport (Environment Canada, 1981). Attempts have been made to relate the intensity of an urban heat island to parameters such as population size and wind speed. Oke (1973) claims that by night a town is warmer than the surrounding country, on average, by $(P^{\frac{1}{4}}/(4\ \bar{u}^{\frac{1}{2}}))^{o}C$ where P = population and $\bar{u}$ = mean wind speed (m/s). However, any single formula cannot account for all the variables. The characteristics of an urban heat island are related to the intrinsic nature of the city (size, building density, land use distribution, etc) as well as external influences such as the climate, prevailing weather and seasons. In Southern Ontario, towns or cities with populations greater than approximately 40,000 appear to generate sufficient heat to promote the formation of an urban heat island.

Oke (1982), in an extensive overview paper, summarizes the microclimate effects characteristic to an urban centre as opposed to a rural region, in the table below.

| Cause | Effect |
|---|---|
| Air Pollution and Canyon Geometry | Increased Absorption of Incoming Solar Radiation |
| Air Pollution | Increased Incoming Longwave (Heat) Radiation from the Atmosphere to the Surface |
| Canyon Geometry | Decreased Outgoing Longwave Radiation Loss (Intercepted by Buildings before lost to Atmosphere) |
| Stacks, Buildings, Traffic | Anthropogenic Heat Source |

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| Cause | Effect |
|---|---|
| Construction Materials, Surface Roughness of Urban Centre | Increased Heat Storage |
| Waterproof Construction Materials | Decreased Evapotranspiration |
| Canyon Geometry | Decreased Total Turbulent Heat Transport |

The combination of these effects and constraints add up to a self-contained urban heat dome. The warm air rises from the city centre. However, the heat island intensity declines rapidly with height from the surface, and as the rising air cools, it will descend on the outskirts of the city. Thus a circulation (based on the same heat principles as the lake breeze circulation), may be set up within this heat dome (Hewson and Olsson, 1967), (Figure I-6). However, calm conditions must exist for the formation of a heat island dome. In reality, winds are not likely to remain calm thoroughout the lower atmosphere for very long. Hence, the more common form of this thermally-modified layer is that of an internal boundary layer entrained in the direction of the wind (Oke, 1982), (Figure I-6).

By day the urban boundary layer increases in depth with time in accordance with the growth of the rest of the mixed layer in the lower atmosphere. Thus by mid-day the urban boundary layer may be .5 to 1.5 km in depth, depending on the heat flux at the surface and the stability of the prevailing air mass (Oke, 1982). As well, the presence of low clouds are more effective in limiting the heat island intensity than is the same amount of high cloud. The presence of the city and its urban boundary layer may be evident by a slight doming of the normal mixed layer (by up to about .25 km), (Spangler and Dirks, 1974). Downwind of the city, the existence of a daytime rural internal boundary layer leaves the urban-affected air aloft as a heat plume within this rural mixed layer, often extending 10's of km (Oke, 1982).

Due to the constant emissions and storage of heat in the urban centre, the sharp temperature changes observed in rural areas

around sunrise and sunset are generally lacking. At night the stability of the rural air is eroded to a depth of 100 to 300 m by the well mixed urban air as the rural air travels across the warm rough city (Oke, 1982). Again, an elevated heat plume is found in the lee of the city, but this time it is surrounded by stable air above and below (Oke and East, 1971). Under light to calm wind conditions, however, the mixed layer created by the urban heating is trapped by stable air on all sides of the "dome", while convective currents re-circulate pollutants within these confines. Pollution gradients between urban and rural areas will be sharpest at night under these conditions, as the vertical (as opposed to lateral) dispersal of pollutants continues. With sunrise, some lateral dispersal may occur as the rural surfaces become warmer (Oke, 1982).

The greatest intensities of the urban heat island are registered during the summer and fall months. This is tied in part to the seasonality of the climate controls (wind, clouds, and air mass stability) as well as reflecting variations in surface covers (snow versus vegetation) and solar influences (angle of incidence of the sun will affect the attenuation of aerosols in the urban canyon geometry, etc). It is interesting to note that the urban heat island effect is more pronounced in the summer whereas peak heating requirements are in the winter. This indicates that anthropogenic heat, although not insignificant, is not a primary cause (Oke, 1982).

## 2.3 Topography

Topographic features generally complicate the dispersion of pollutants, as a function of their size and shape, and proximity to the source. Prominent features block pollutants advected towards their face. Deep valleys tend to recirculate pollutants. Fumigation events can occur frequently, at the top of the feature, or along the face (Figure I-7).

The Niagara Escarpment, as the major topographic feature in Southern Ontario, can complicate the dispersion of pollutants emitted

near its base. Other less pronounced topographic features of the Golden Horseshoe, such as prominent ridges, hills and valleys, may have similar influences on dispersion, with the significance and extent of the effect being more or less proportional to their size.

The escarpment face is oriented towards the east in the northern sections, and the north in the regions between Hamilton and Niagara Falls. Therefore, much of the preferential heating which would normally drive slope drainage winds upslope during the day is absent over much of the escarpment. This promotes daytime trapping of pollutants emitted near the base. Winds from the direction of the low to the high ground will direct emissions from below the face into the side of the escarpment (ideal fumigation conditions). Winds from the direction of the high to the low ground will cause a plume emitted near the base to meander within the wake region, and will impede dispersion and dilution, creating high ground level concentrations near the stack. Emissions from an effective stack height greater than the elevation of the escarpment will disperse adequately if winds are from the high to the low ground. However, if winds are from the low to the high ground, this same stack could emit pollutants which will, in all likelihood, fumigate on the high ground, or create high ground level concentrations as the plume disperses under unstable conditions. Regions of the Golden Horseshoe which are bordered on more than one side by the escarpment have the potential to experience especially poor dispersion of pollutants emitted below the escarpment.

## 2.4 Combined Effects

A number of examples of the combined occurrence of lake breeze, urban heat island and topographic influences exist within the Golden Horseshoe region of Southern Ontario.

The presence of an urban heat island will strengthen a lake breeze circulation, and most likely increase the occurrence of lake breeze phenomena (Hewson and Olsson, 1967). The lake breeze circulations will recirculate pollutant emissions from an urban area. For example, a 1974 study in Toronto found the trapping of ozone within

a lake breeze recirculation cell (Lusis et al., 1976). The thermal contrast between the lake and the urbanized land is greater than it would be between the lake and rural lands. The circulation cell will have a greater vertical extent but will probably not extend as far inland. A heat island the size of Toronto may prevent a land breeze flow at night, as the urban surfaces may not cool sufficiently to create the necessary temperature differential (Figure I-8).

A topographic feature situated near the lake may disrupt a lake breeze circulation cell, by forcing the air to rise before it is heated sufficiently. This may serve to weaken the circulation, although a significant portion of the pollutants emitted from a stack in this zone can be expected to fumigate against the face of the feature. If the lake breeze circulation cell formation is sufficiently retarded by the topography, trapping of the pollutants below the feature will occur. However, on very warm summer days, the circulation cell can be expected to be present, and although its vertical dimensions may increase, the horizontal dimension inland will definitely decrease. A 1974 meteorological study of the Wesleyville Ontario Hydro site (ACRES, 1974), recorded that the effects of a prominent ridge appear to have blocked inland penetration of the lake breeze, with further evidence of a return flow to the lake at levels near 700 m. Under light regional winds, the cooler lake air may extend over a topographic feature, if the feature is in close proximity to the lake, although it is unlikely that one circulation cell will form in this case; rather, several small localized convective cells may form.

An urban heat island bordered by a topographic feature is likely to experience a recirculation of its pollutants (trapping) more frequently than an urban centre located on a flat plane, as it may be protected from regional winds from above the feature. The heat plume advected under regional winds towards the topographic feature would tend to fumigate either against the face or on the high ground at the top of the feature. Either case represents increased ground level concentrations from the urban centre, or a stack located near an urban centre, as a consequence of the presence of the topographic feature.

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The greatest likelihood of occurrence of serious pollution episodes can be anticipated with the concurrence of a lake breeze and an urban heat island in proximity to a prominent topographic feature (Figure I-9). The city of Hamilton which is surrounded on three sides by the Niagara Escarpment and on the other side by Lake Ontario is a good example of this situation. The urban heating right at the shoreline allows a large thermal contrast to develop between the land and the lake, often promoting a series of cells, including a strong 24-hour lake breeze in the vicinity of the heavy industry near the shoreline. The diurnal cell dimensions, however, are generally confined by the escarpment, trapping the pollutants. Relatively strong regional winds are required to disperse some of these suspended pollutants from their confinement. High ground level concentrations are frequently recorded in Hamilton as a result of these combined influences, especially during the warm months.

## 3. RATIONALE FOR USE OF AIR DISPERSAL CONSTRAINTS

The objective of this work component was to discuss the rationale for the use of air dispersal constraints as important factors in the identification of a suitable site for an incinerator. Each of the constraints represent specific circumstances and situations which can result in poor dispersion conditions, with the extent and severity of such conditions dependent upon the factors and parameters discussed in the previous section.

Emissions to the atmosphere represent the major potential environmental impact that might arise from the operation of a waste incinerator. The mechanism of this potential impact consists of three components:

- emission
- dispersion
- receptor impact.

Optimal control of emissions at the source through the use of best-available incineration and emission control technology must be viewed as the most important component of any overall control strategy used to minimize this potential impact. However, a number of factors warrant the use of other avoidance-type measures as part of the overall control strategy. These are:

- the great variety of materials which must be incinerated, giving rise to the potential for unanticipated emissions,
- the lack of emission and point-of-impingement standards that can be used to precisely specify system performance relative to many of the trace contaminants which might be emitted by a hazardous waste incinerator,

ORF

- the lack of any feasible mitigative measures that can be applied on an operational basis once emissions have occurred.

The selection of sites which minimize the potential for poor dispersion to occur is one of the obvious avoidance measures that can be used to reduce the chance of any significant impact. By avoiding areas where air dispersal constraints such as lake breezes, urban heat islands and topographic features occur, both the frequency and intensity of periods in which abnormally high pollutant levels might occur are reduced. In addition, the predictability and consistency of dispersion conditions that will prevail are much greater in the absence of such influences, so that any potential impact that needs to be considered can be predicted with much greater confidence. For these reasons the avoidance of sites which involve factors leading to poor or complex dispersion conditions is considered to be an important criterion in the siting of a waste incinerator.

ORI

## 4. AIR DISPERSAL CONSTRAINTS WITHIN THE GOLDEN HORSESHOE

Meteorological and topographic features which could result in the occurrence of poor dispersion conditions in specific sectors of the Golden Horseshoe were identified in earlier studies (Ontario Research Foundation, 1982). The objective of this present work activity was to define in further detail the geographical extent of these influences and to enable future consideration with other environmental, engineering and planning factors. The results have been graphically summarized on a 1:126,000 map of the area and this has been inserted in the pocket on the back cover of this report.

The subjective nature of the interpretations and assessments upon which this map is based must be emphasized. For example, the extent of areas over which poor dispersion conditions will exist as a result of lake breezes or other influences are subject to diurnal, seasonal and annual variations. Thus, the graphical representations of boundaries of each influence provided on the map should not be regarded as precise and accurate demarcations of the presence, or absence, of these influences. Rather, they represent the approximate zones of most probable influence that could be expected to occur under normal climatic conditions in Ontario.

It should also be noted that the study did not include any detailed consideration of the potential impact of either "average" or worst case emissions on receptors in the vicinity of the proposed facility. The relative potential for significant impact has been considered only very briefly, and more detailed assessments will form part of future studies.

As discussed in Section 2, the extent and intensity of lake breeze effects on dispersion show considerable seasonal variability, with the most pronounced boundary layer formation occurring during the daytime in the summer months. Under these conditions the slope of the internal boundary layer (Figure I-5) near the shoreline varies from 1:4 to 1:13 depending on such factors as solar intensity,

land form, etc. For example, assuming an effective stack height of 100 m for an incinerator near a shoreline, the furthest inland point of fumigation would occur at approximately 1.3 km. If the stack was located approximately 1.3 km inland, emissions would occur just within the internal boundary layer, resulting in poor vertical dispersion for at least a few hundred metres due to the stable air above the boundary layer. On this basis, a stack less than or equal to approximately 100 m in height, located more than approximately 2 km inland, can be expected to result in good dispersion under all summer lake breeze conditions. However, a stack greater than 100 m in height should be situated further than 2 km inland to prevent fumigation. The criterion used to define the extent of the lake breeze regime in the initial inventory of climatological conditions prevailing in Southern Ontario (Ontario Research Foundation, 1982) was based on the assumption that 100 m or less was a reasonable height for an incinerator stack.

During the spring and fall months, a smaller temperature differential exists between the land and the water. Therefore the internal boundary layer growth will not be as well defined (i.e., a more gradual slope). Fumigation would occur further inland. An internal boundary layer slope of approximately 1:40 would require a relatively tall stack to be approximately 5 km from the shoreline to ensure emission into the well-mixed internal boundary layer.

Light onshore regional winds also can promote internal boundary layer formation during daylight hours, with the same implications relative to fumigation occurrences. The approximate frequency of occurrence (expressed as a percent of time) of these conditions in the Golden Horseshoe are summarized below:

| | Light Regional Winds | | | |
|---|---|---|---|---|
| | Toronto (E,SE,S) | Hamilton (NE,E) | St. Catharines (N) | Lake Breezes |
| Spring | 27% | 30% | 10% | 11% |
| Summer | 25% | 22% | 9% | 17% |
| Fall | 26% | 21% | 9% | 5% |

The light regional wind values represent all hours of the day and therefore should be divided by ∿ 2 to give a realistic estimate of the frequency with which such conditions occur. On the basis of these more detailed considerations, it is concluded that an incineration facility with an approximate stack height of 100 m or less should not be located within 5 km of a shoreline in order to avoid poor and complex dispersion during all seasons. This criterion is considered appropriate for present and subsequent evaluations of candidate areas and sites.

The regions designated as urban heat islands are towns or cities which can be expected to promote enough heat to create a substantial temperature differential with the surrounding rural regions. Usually, the maximum heating can be expected to take place at the city centre (see Section 2). Rising warm air and pollutants will descend at the edges of the city, or downwind of the city, depending upon prevailing wind conditions. At night, under calm to light winds, the heat generated creates a mixing zone amidst stable rural air and recirculates the emissions. Thus, the effects are most severe at night during the summer months under calm conditions.

Most urban centres are located near the shoreline in the Golden Horseshoe. The heat of an urban centre will intensify an existing lake breeze circulation or aid in forming one. This increases the frequency of lake breeze occurrences near an urban centre and promotes the occurrence of fumigation within the urban centre for stacks near the shore.

Topographic effects are shown on the maps of the escarpment. A stack located relatively near to the base of the escarpment can be expected to result in complex plume dispersion patterns, and the consequences become more severe with closer proximity (Figure I-7). Fumigation against the face of the escarpment can occur under a) moderate to strong winds blowing towards the escarpment and b) stable, light wind conditions with winds blowing towards the escarpment.

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Cold air drainage at night down the face can create inversion situations at the base, restricting dispersion. A stack situated near the base of the escarpment will experience a meandering, stagnant plume if the winds are from above. In areas where the escarpment is near the lake, the lake breeze will advect the emissions against the escarpment face, before continuing with a disrupted and perhaps restricted cell circulation. Entrapment against the escarpment also may occur. Stronger regional winds which may serve to disintegrate lake breeze and urban heat island circulations may, at the same time, trap pollutants at the base of the escarpment.

Areas not under the influence of air dispersal constraints can be expected to provide better, and more predictable, dispersion of emissions than areas influenced by these factors. The occurrence of one or two meteorological constraints implies that a thorough review of the specific circumstances would be required before using such an area for the siting of an incinerator. Any area having the simultaneous occurrence of all these constraints is unlikely to be a satisfactory incinerator site in terms of dispersion conditions. The primary reason for avoiding poor and unpredictable dispersion conditions is to ensure that downwind concentrations of any emissions which might occur will not reach ground-level concentrations in excess of recommended levels or standards. Thus, the need exists to also consider the relative potential for impingement of emissions downwind of candidate areas. Generally, it is the potential impacts of emissions associated with the day-to-day operation of the facility which are compared to recommended levels and criteria. However, the need also exists to assess the potential impact of unforeseen events, such as an accidental spill or explosion at any of the facility components, i.e., landfill, physical/chemical treatment plant and incinerator. Such considerations will be components of future studies in which candidate areas and sites will be evaluated in further detail.

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# APPENDIX I

## Diagrams Illustrating Mechanisms of Climatological Influences

FIGURE I-1

# FORMATION OF THE LAKE BREEZE CIRCULATION

On a relatively calm day, some hours after sunrise, the land surface is heated, becoming warmer than the lake surface.

Cool air from the lake replaces the rising warm air.

The cool lake air warms as it travels inland over the warm land surface and soon starts to rise.

Circulation cell develops based on the replacement of displaced air. Full development is reached in mid-afternoon.

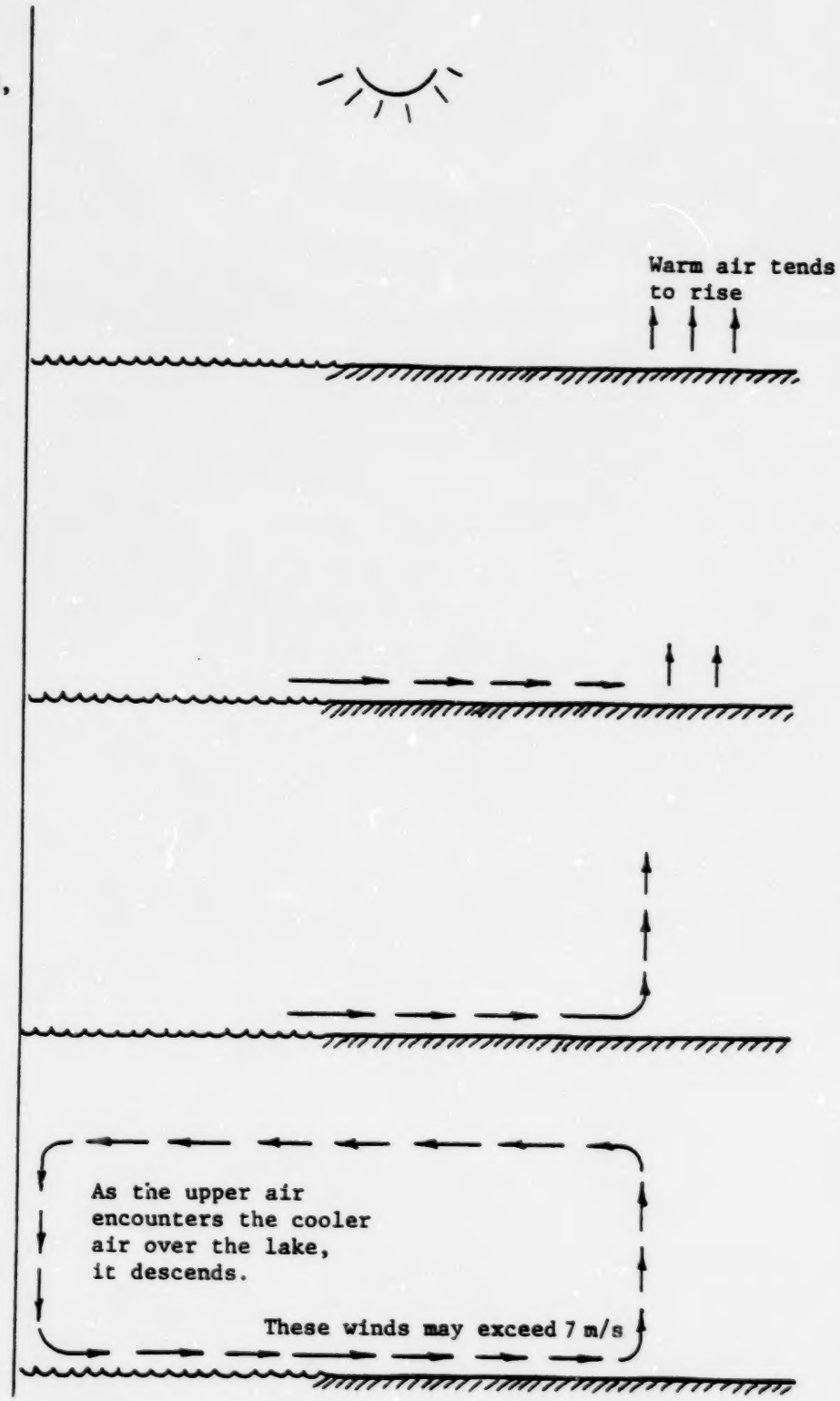
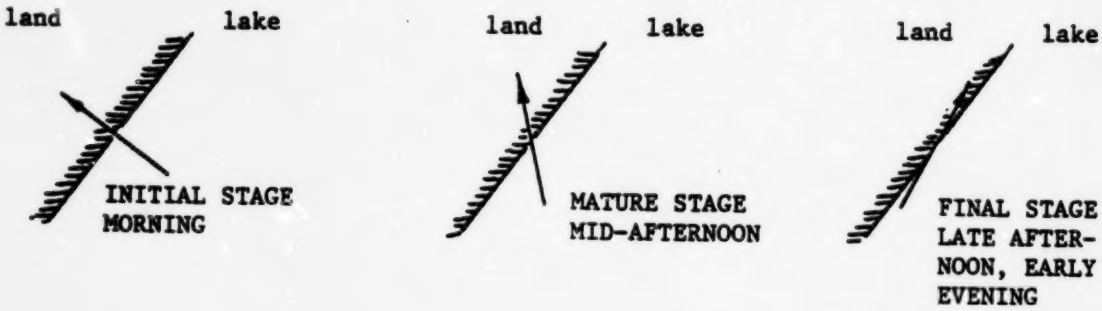


FIGURE I-2

## CORIOLIS FORCE EFFECTS

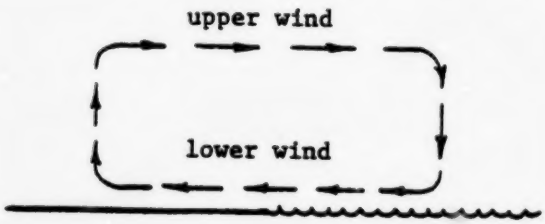
Due to the rotation of the earth, local winds tend to be deflected to the right in Southern Ontario. The lake breeze is initially perpendicular to the shoreline due to the manner of its formation. However, by the late afternoon it tends to become almost parallel with the shore.

Lower wind*




Upper wind*

* Note

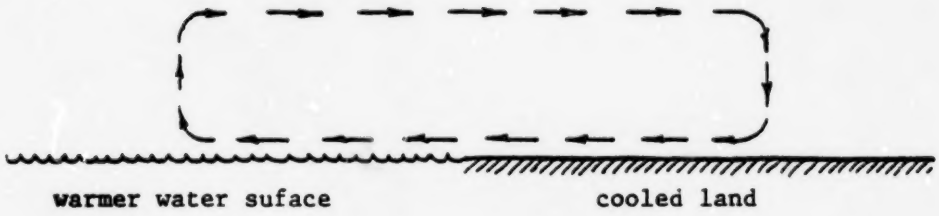



(FROM HEWSON AND OLSSON, 1967)

FIGURE I-3

# THE LAND BREEZE

The general driving force behind the lake breeze circulation is the amount of incoming solar radiation. As the sun sets, the land cools through the process of outgoing longwave radiation, and the lake breezes die. During the night, the land surface often cools at a faster rate than the lake surface, especially on a clear night, giving rise to a land breeze circulation.




The circulation is a reverse of the day-time lake breeze and is usually much less intense due to a smaller temperature differential between the land and the water.

FIGURE I-4

## SEASONAL SHORELINE CIRCULATIONS UNDER LIGHT REGIONAL WINDS

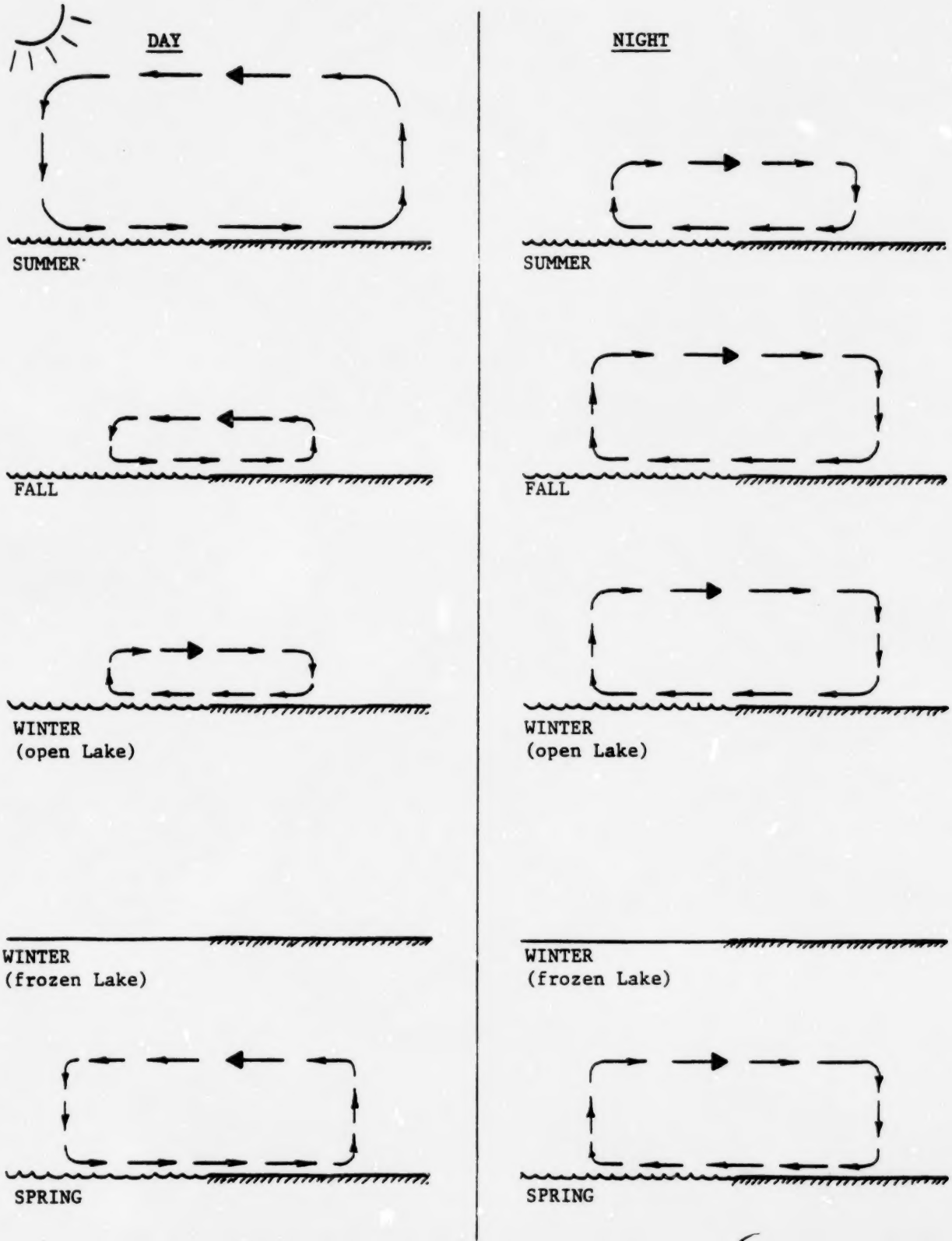
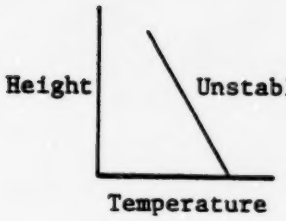


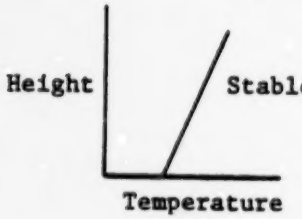
FIGURE I-5

# THE INTERNAL BOUNDARY LAYER

**Stability**

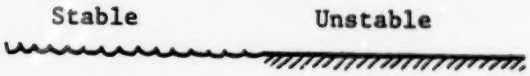



Buoyant atmosphere. Vertical air motions enhanced.

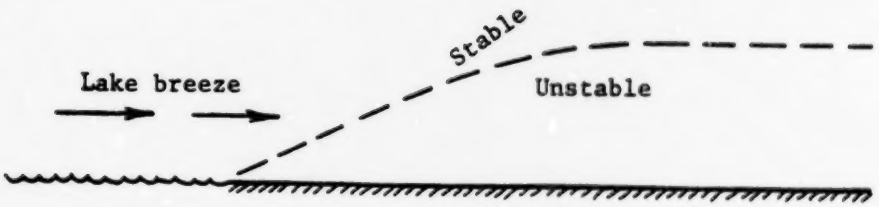



Vertical air motions suppressed.

During the warm months, in the day, the lake surface will be cooler than the air.

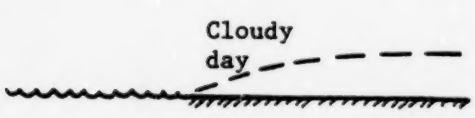


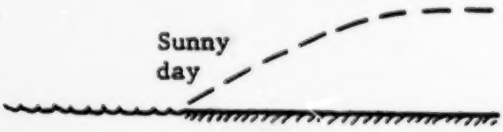

During the day, the land surface becomes warmer than the air as the sun heats the land and unstable conditions develop.




As the lake breeze advects the colder stable air over the land, during the day, the stable air will tend to act as a lid, forming an "internal boundary layer".

The height of the internal boundary layer is controlled partly by the intensity of the incoming solar radiation. For example:



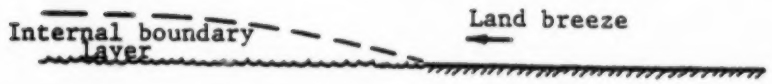




...2/..

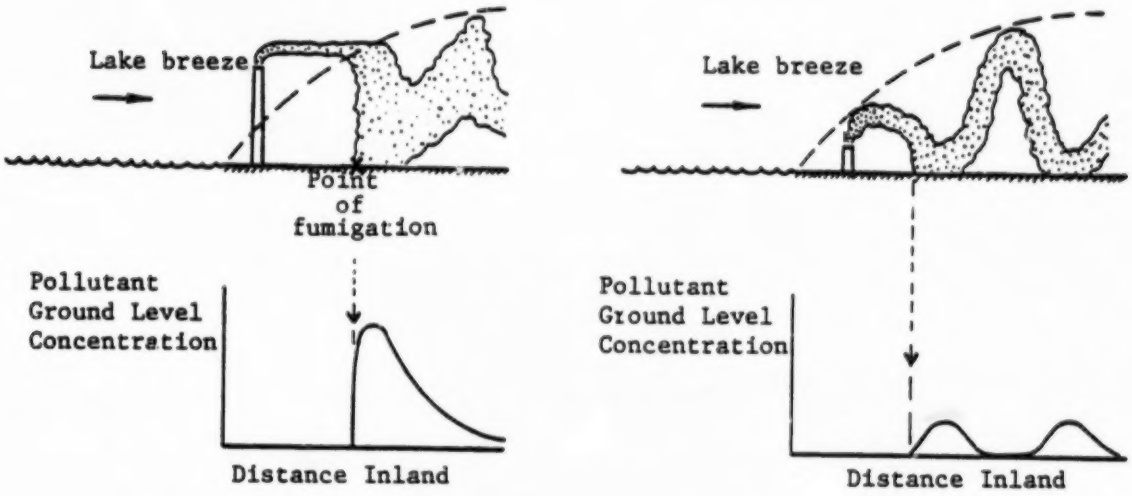
FIGURE I-5 (cont.)

# THE INTERNAL BOUNDARY LAYER (cont.)

At night the lake surface retains heat and remains warmer than the air. Therefore unstable conditions prevail. However, over the land the surface has cooled at a faster rate than the air, designating stable conditions. The reverse lake breeze flow creates a relatively weak internal boundary layer over the lake.




Superimposing a stack into this environment can create variable plume behaviour patterns, as a function of the height of the internal boundary layer combined with the height of the stack (and the plume).




At the point of fumigation, very high ground level concentrations occur. When the plume is emitted within the internal boundary layer, lower ground level concentrations result at any one location.

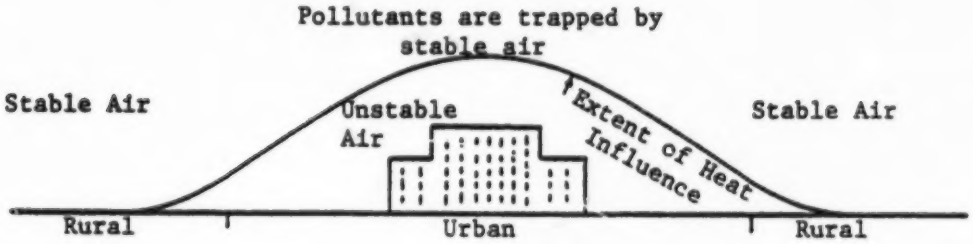
Pollutants emitted at night from a tall stack, which do not encounter the shallow internal boundary layer over the lake may be transported out over the lake, only to be brought back inland with the reversal of the breeze in the late morning.

FIGURE I-6

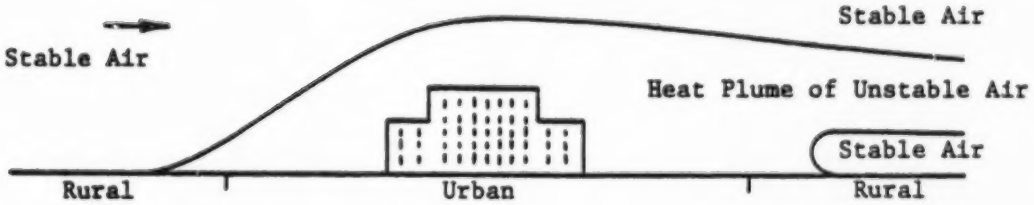
# URBAN HEAT ISLAND

## The Nocturnal Urban Boundary Layer Under Relatively Clear Skies

No Wind



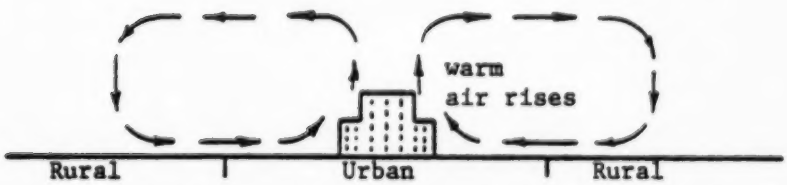

Light Regional Wind




The following factors combine to inhibit the noctural inversion in an urban centre:

- heat releases (industry and heating,
- heat storage capacity of materials,
- aerodynamic roughness enhancing mixing,
- radiational characteristics of urban pollutants.

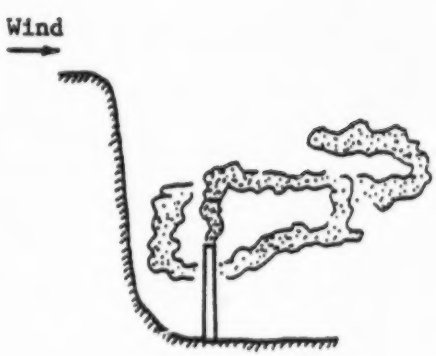
## Urban Heat Island Circulation



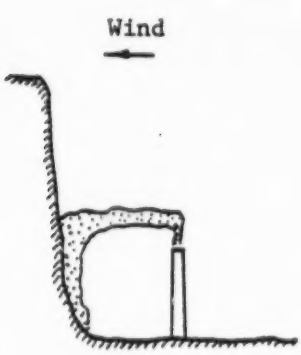

The temperature differential between the urban and rural areas is sufficient to initiate a circulation under relatively calm conditions, during all seasons, day or night.

FIGURE I-7

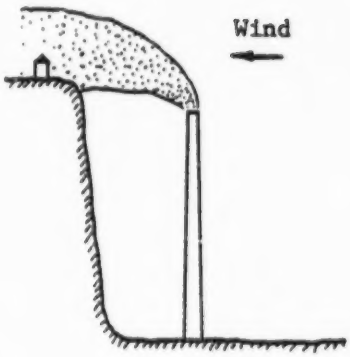
# TOPOGRAPHIC EFFECTS




Meandering Plume in the Shelter of a Steep Slope



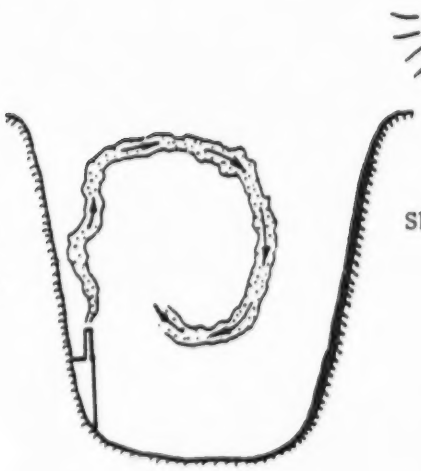

Plume Trapped by the Slope




Plume Results in High Ground Level Concentrations at the top of the Slope

Valley Circulations

As the south facing wall of the valley warms up from the sun, the warm air rises, and a circulation is set up within the valley.

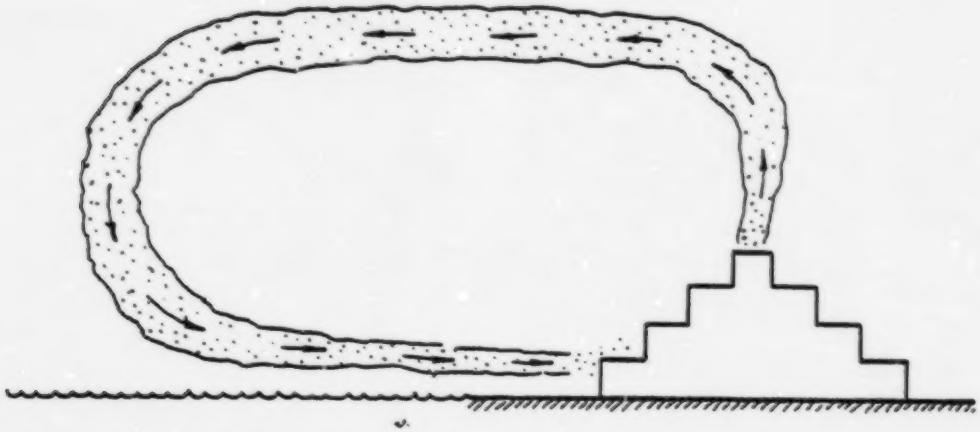



At night the flow of pollutants will be down the length of the valley, and up the valley during the day, tending to "reshuffle" the pollutants.

FIGURE I-8

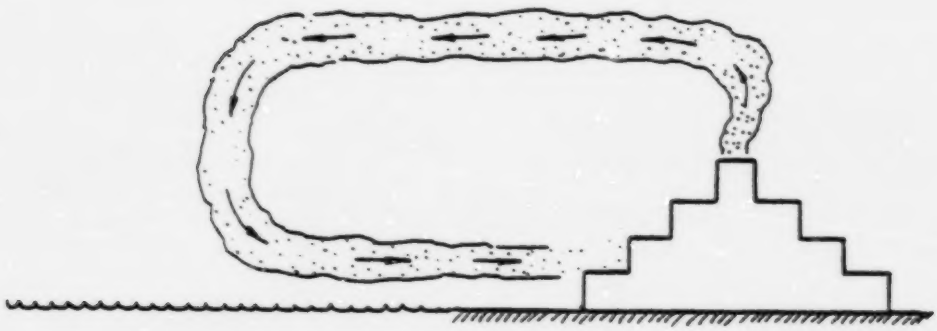
# URBAN HEAT ISLANDS NEAR THE LAKE

DAY



The heat island effect would reinforce a lake breeze circulation, as the land surface is warmer closer to the shore, causing the warm air to rise higher.

NIGHT



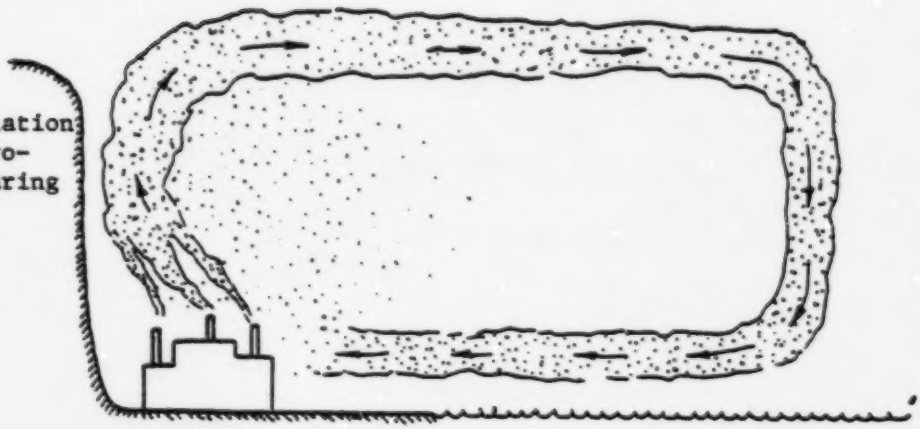
The land surface is not cooler than the water surface due to the stored and emitted heat in the urban centre. Therefore a land breeze cannot form. A weaker lake breeze is initiated than would be during the day, local to the part of the shoreline near the urban centre.

Note: In both cases the pollutants are returned to the urban centre.

FIGURE I-9

# LAKE BREEZES, URBAN HEAT ISLANDS AND TOPOGRAPHIC INFLUENCES COMBINED

DAY
AND
NIGHT

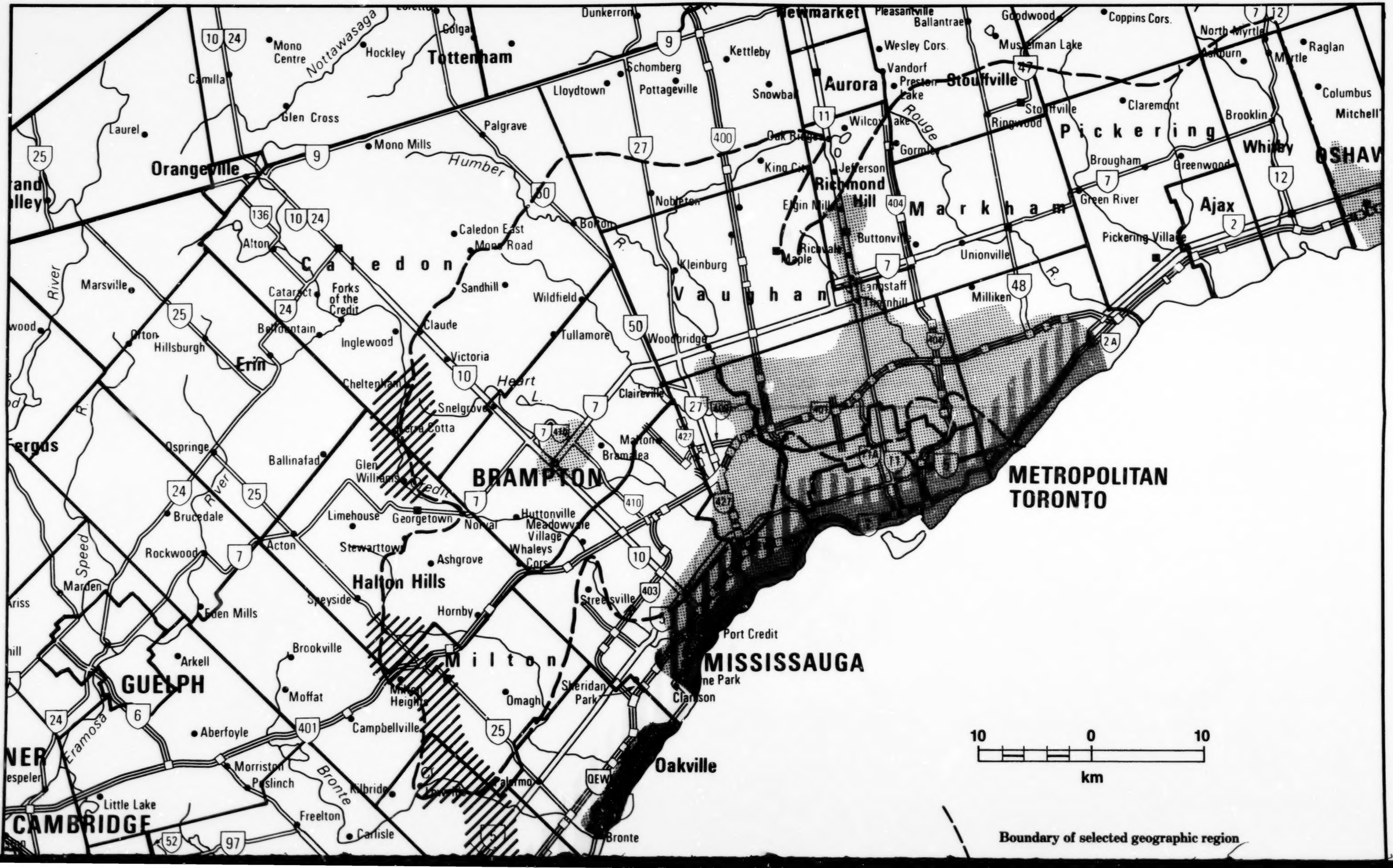


Note:
The circulation is more pronounced during the day.

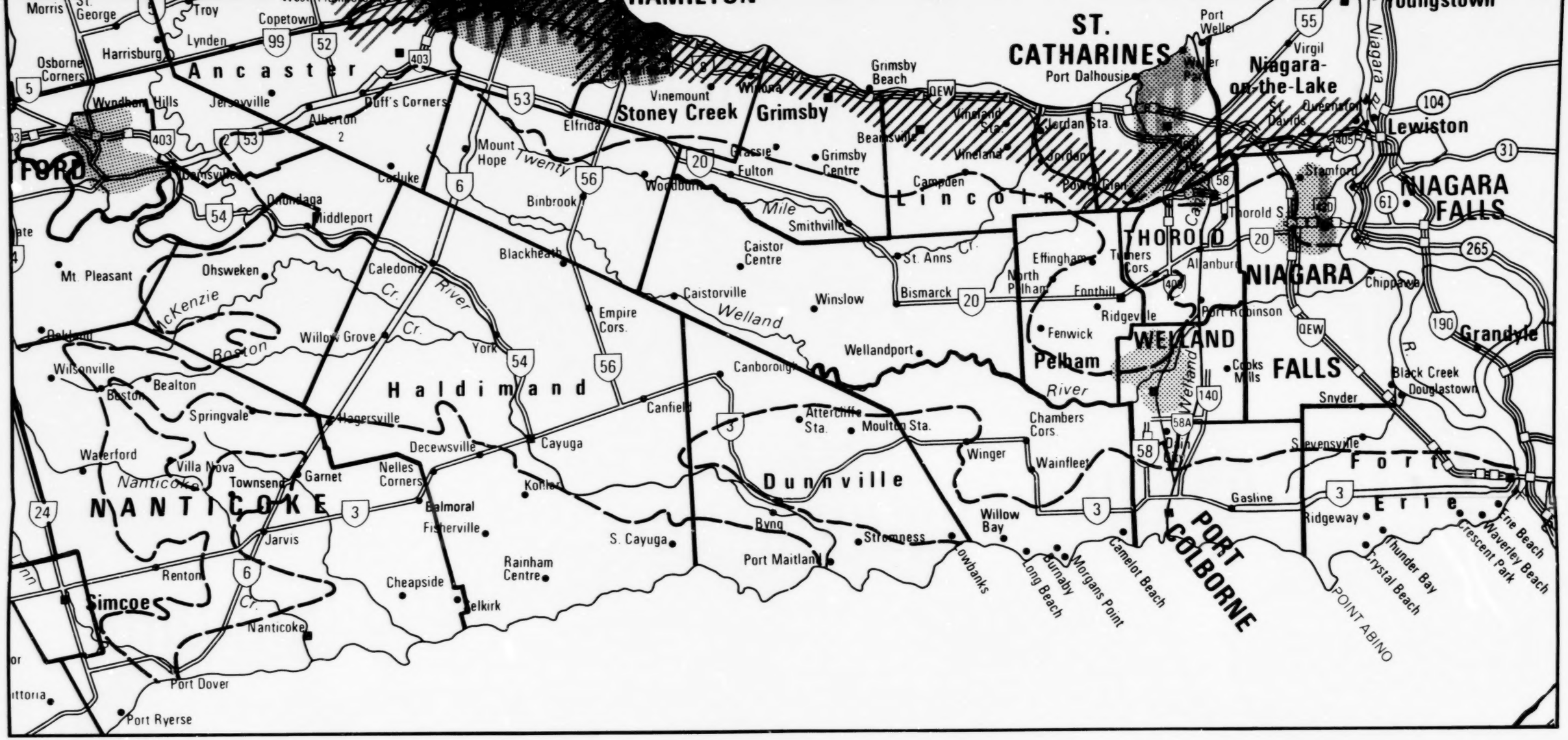
When regional winds prevail and do not allow the lake breezes to form, the pollutants will be trapped by the topography, whereas flat regions can expect the regional winds to disperse the pollutants recirculated by the lake breeze/urban heat island cell.

Hamilton, Ontario is surrounded on three sides by the Niagara Escarpment and on the other side by Lake Ontario. Serious pollution episodes develop in the summer when thermal contrasts between the lake and land are greatest.

# Map 1 Atmospheric dispersion



METROPOLITAN TORONTO
BRAMPTON
Halton Hills
Milton
MISSISSAUGA
Oakville
BURLINGTON
HAMILTON
GUELPH
CAMBRIDGE
Ancaster
FORD
ST. CATHARINES
Stoney Creek
Grimsby
Lincoln
THOROLD
NIAGARA FALLS
WELLAND
Niagara-on-the-Lake
Port Credit
Streetsville
Georgetown
Acton
Rockwood
Brucedale
Ospringe
Fergus
Ballinafad
Limehouse
Stewarttown
Ashgrove
Speyside
Hornby
Eden Mills
Arkell
Brookville
Moffat
Aberfoyle
Campbellville
Morriston
Puslinch
Little Lake
Freelton
Carlisle
Kilbride
Omagh
Sheridan Park
Clarkson
Bronte
Port Dalhousie
Grimsby Beach
Vinemount
Elfrida
Mount Hope
Binbrook
Smithville
Caistor Centre
Caistorville
Winslow
Bismarck
Fonthill
Ridgeville
Fenwick
Effingham
North Pelham
Port Robinson
Chippawa
Youngstown
Lewiston
Virgil
Queenston
Stamford
Thorold S.
Allanburg
Grandyle
Westover
Millgrove
Waterdown
Clappisons Cors.
Rockton
Peters Cors.
Greensville
Troy
Copetown
Lynden
Harrisburg
Osborne Corners
Wyndham Hills
Jerseyville
Duff's Corners
Alberton
Carluke
Dundas
Middleport
Ohsweken
Mt. Pleasant
Caledonia
Willow Grove
Empire Cors.
Blackheath
Twenty Mile Creek
Welland River
Bronte Creek
Credit River
Speed River
Eramosa River
McKenzie Creek
Boston Creek
Niagara River
10 0 10
km
Boundary of selected geographic region




## Legend

**Zones of influence**

- 2 km lake breeze
- 5 km lake breeze
- Topographic features
- Urban heat islands

Consultant: Gartner Lee Associates Ltd. in conjunction with Ontario Research Foundation

These zones of influence show the approximate areas in the Golden Horseshoe that are most frequently subject to atmospheric conditions that inhibit good dispersion of emissions to the atmosphere. This map is based on information from secondary sources plotted at a regional scale. (See Gartner Lee Associates Ltd. / Ontario Research Foundation, *Atmospheric Dispersion Influences: Golden Horseshoe*, OWMC, May 1983.)

POOR

QUALITY

ORIGINAL